A high-resolution pre-operational forecast model of circulation on the Texas-Louisiana continental shelf and slope

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A new pre-operational model of circulation over the Texas-Louisiana continental shelf and slope, based on the Regional Ocean Modelling System (ROMS) is presented. The model is designed with a number of practical applications in mind: to predict oil spill trajectories, investigate the mechanisms controlling seasonal hypoxia, and to understand the origins of harmful algal blooms on the Texas-Louisiana continental shelf and slope. This model consists of two parts: the hindcast and pre-operational components. The hindcast model is forced with the observed freshwater fluxes from the nine major Texas and Louisiana rivers, surface winds, and heat and salt fluxes from North American Regional Reanalysis (NARR) dataset. The hindcast simulations are carried out over an eight-year period (February 2003–June 2011). The pre-operational model, which provides nowcast and a five-day forecast, starts from July 2011 with a different surface momentum and heat flux forcing from the Global Forecast System (GFS). Both hindcast and forecast models are nested to the Gulf of Mexico HYCOM (Hybrid Coordinate Ocean Model) which provides an estimate of the circulation in the deep Gulf. Model performance is quantified based on the model skills calculated using measurements from the Texas Automated Buoy System (TABS), coastal water level stations and satellite altimetry data. The model is able to reproduce not only the seasonal pattern of sea surface height (SSH), temperature, and velocity fields, but also the strong sea-breeze-driven near-inertial surface currents, which have been found dominant in this region during the summer months.

AUTHORS' BIOGRAPHIES

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include examining plankton bloom dynamics, formation and destruction of continental shelf hypoxia, and real-time surface current forecasting.

INTRODUCTION

The Texas-Louisiana coastal region is a broad continental shelf and slope with several significant environmental problems. As one of the energy centres in the world, there are more than 1.2 billion barrels of oil passing near Texas and Louisiana wetlands, bays and beaches each year. Oil spills happen more than 900 times per year on average on the Texas and Louisiana shelf and slope. Therefore, it is of great importance to predict the trajectories of these spills to reduce the oil damages to marine resources (eg, the *Deepwater Horizon* oil spill in 2010, the largest oil spill in US history). One effective way to track these pollutants is using surface currents from a high-resolution numerical model.

Harmful algal blooms (HABs) occur on the Texas-Louisiana shelf with increasing frequency and pose a significant threat to human and environmental health. They also have economic and cultural implications, especially in coastal communities dependent on harvesting seafood and tourism. *Karenia brevis*, a toxic dinoflagellate, is the most common cause of HABs in the Gulf of Mexico.[1] Impacts of *K. brevis* include massive fish kills, marine mammal, sea turtle and sea bird mortalities, benthic community die-offs, and public health effects from shellfish contamination and inhalation of air-borne toxins. Results from a numerical experiment[2] demonstrate the potential importance of surface convergence due to Ekman transport in forming blooms of *K. brevis* along the Texas coast. A high-resolution circulation model can improve the ability to track the origins of harmful algae blooms species on the Texas and Louisiana shelf and slope.

Furthermore, coastal hypoxia, ie, water of dissolved oxygen concentration less than 1.4ml l^{-1}, is another significant environmental problem in this region that is increasing in severity and frequency due to anthropogenic inputs of nutrients into the coastal environment.[3,4,5,6]

Hypoxia can have detrimental effects on marine organisms and therefore can lead to catastrophic consequences for coastal ecosystems and for local economies that rely on commercial and recreational fisheries resources.[7] The area affected by coastal hypoxia on the Texas and Louisiana shelf and slope in the northern Gulf of Mexico has averaged over 15 000km^2 for the years 1993–2006, and reached 20 500 km^2 in 2007, making it the largest area of hypoxic water of the western Atlantic Ocean region and second largest worldwide.[8]

Understanding the mechanisms controlling hypoxia and forecast of coastal hypoxia area also require a sophisticated coastal model. The importance of shelf circulation in influencing the area extent of shelf hypoxia has been highlighted[5]. Here, a forecast is used based on the model presented in[5], combined with a parameterisation of benthic respiration, based on[5], to do a short-term prediction of hypoxia prior to an annual monitoring cruise in July 2011 (see http://gulf.hypoxia.net). The oxygen model was configured in exactly the same way as reported,[5] except with a new hydrodynamic base model. Hypoxia area was calculated using a critical value for oxygen that resulted in the best match for area measure during a prior cruise in June (see http://hypoxia.tamu.edu). The predicted area 1 week before the cruise was 16 818km^2, with an observed area of 17 520km^2. It is hoped to further develop this aspect of the model and use it to make annual predictions of hypoxic area in the northern Gulf of Mexico.

The seasonal circulation on the Texas-Louisiana shelf is mainly wind-driven with a strong contribution from buoyancy forcing near the Mississippi and Atchafalaya Rivers (eg[9,10]). In the summer months, when winds are weakly upwelling favourable, fresh water tends to pool on the shelf and thus intensify the local stratification. During winter, the winds reverse to downwelling favourable, enhancing downcoast flow of fresh water, and with the addition of frontal passages that mix the water column, the stratification created in summer is reduced. This seasonal pattern is modulated between years by changes in prevailing winds and the magnitude of the fresh water discharge, and it controls many important shelf processes: transport of harmful algae blooms, nutrient cycling, and seasonal hypoxia.[2,5,6,11]

As for shorter time scales of hours to days, the circulation on this shelf is mainly driven by land/sea breeze especially during summer months. The characteristics of land/sea breeze and their associated near-inertial motions have been investigated in detail.[12,13] Land/sea breeze can drive significant near-inertial currents on the Texas-Louisiana shelf because of the coincidence of the period of land/sea breeze (~1 day) and the inertial period of the ocean (~1 day). These near-inertial currents represent the strongest non-storm induced currents on this shelf, and can reach more than 60cm s^{-1}. These motions and their associated vertical mixing are important to understand and protect the coastal environment (eg, prediction of oil spill trajectory). It is understood from increased knowledge of the dynamics of inertial currents that there is a need for a complex high-resolution model to better resolve these short timescales.

On the slope area and in the deep-water of this region, the current is dominated by the offshore Loop Current (LC) and Loop Current Eddies (LCEs).[14] The currents associated with LC and LCEs are energetic, and can be greater than 1.5m s^{-1}. The anticyclonically rotating LC typically has a bulging phase, where the LC meanders penetrate deeply into the GOM and interacts directly with the Texas and Louisiana shelf and slope before exiting to the east through the Florida Straits.[15] Surrounding a bulging LC is a complex eddy field including both cyclonically (cold core eddies) and anticyclonically (warm core eddies) rotating eddies.[16,17] The LC bulge eventually may pinch off and form a warm core ring, which moves to the west onto the Texas and Louisiana shelf and slope at speeds of a few km d^{-1}.[18] The LC and pinched LCEs have significant influence on the dynamic environment of Texas and Louisiana shelf and slope, therefore it is necessary to include them in our numerical model.

This paper presents the implementation of a high-resolution numerical model to both hindcast and pre-operational prototype forecast ocean conditions over the Texas and Louisiana shelf and slope, focusing on the ability of the model to reproduce observed temperature, sea surface height, and velocities structure from hourly to seasonal time scales. The data used for model validations in this manuscript are all from operational observational networks.

This paper begins with a description of the numerical model, after which the observational data used for model validation are discussed. Following this, the model skill is defined and used to quantify the model performance later in the manuscript. Comparisons of the observations and hindcast model output are then given, followed by details of the pre-operational model setup and some results of simulated salinity from the model. The paper ends with a summary and future work.

HYDRODYNAMIC MODEL CONFIGURATION

The simulations were performed using the Regional Ocean Modelling System (ROMS, 3.4). ROMS is a free-surface and terrain-following hydrodynamic ocean model widely used by the scientific community for a diverse range of applications.[19,20] The model domain covers the entire Texas and Louisiana shelf and slope area (Fig 1), with a resolution of ~500m near the coast, and ~1–2km on the outer slope area. The model has 30 vertical layers with a minimum water depth of 3m, and a maximum water depth greater than 3000m. The model is configured to use recursive multidimensional positive definite advection transport algorithm for horizontal advection of tracers, third order upwind advection of momentum, conservative splines to calculate vertical gradient, and Meller and Yamada[21] turbulence closure with the Galperin *et al*[22] stability functions.

The Texas and Louisiana shelf and slope model was initialised on 1 Feb 2003, with the initial and open boundary conditions provided by the Gulf of Mexico Hybrid Coordinate Ocean Model (GOM-HYCOM) (http://www.hycom.org). GOM-HYCOM is a hybrid isopycnal-sigma-pressure coordinate ocean model. The model domain includes the whole GOM. The horizontal resolution is 1/25° and it has 20 vertical levels. HYCOM possesses the advantages of the different vertical discretisations to simulate from shallow coastal features region to large scale open-ocean circulation. The hybrid vertical discretisation dynamic transitions between the different coordinates: isopycnal in the open, stratified ocean, terrain-following in coastal regions and constant z level coordinates in unstratified areas, like the surface mixed layer. The HYCOM nowcast/forecast system runs in real time at the Naval Oceanographic Office (NAVOCEANO). Surface atmospheric forcing is from the Navy Operational Global Atmospheric Prediction System (NOGAPS). HYCOM assimilates data from several sources, including along-track satellite altimetry observations, satellite-measured and *in-situ* surface temperature, and vertical temperature profiles from XBTs, ARGO and moored buoys. Assimilations are done with the Navy Coupled Ocean Data Assimilation system (NCODA). The GOM-HYCOM implementation is nested in the Atlantic scale 1/12 HYCOM model. The model outputs are available as daily snapshots at standard Levitus depth levels.

The hindcast model is forced with 2-d wind, and sea surface heat (short wave) and salt fluxes from the North American Regional Reanalysis (NARR) dataset. The forcing has 3-h temporal resolution and 32km spatial resolution so that it is able to resolve the strong land/sea breeze on the shelf. Long wave radiation, latent, and sensible heat fluxes are calculated in ROMS internally. Since the surface heat flux is only prescribed as a boundary condition, there is no feedback from the ocean to the atmosphere heat flux forcing causing drifts in SST occur due to small but persistent errors in heat flux. In order to fix this problem, a uniform Q-correction of 50 Watts/m^2/°C is also used to relax the sea surface temperature to spatially uniform monthly sea surface temperature climatology.

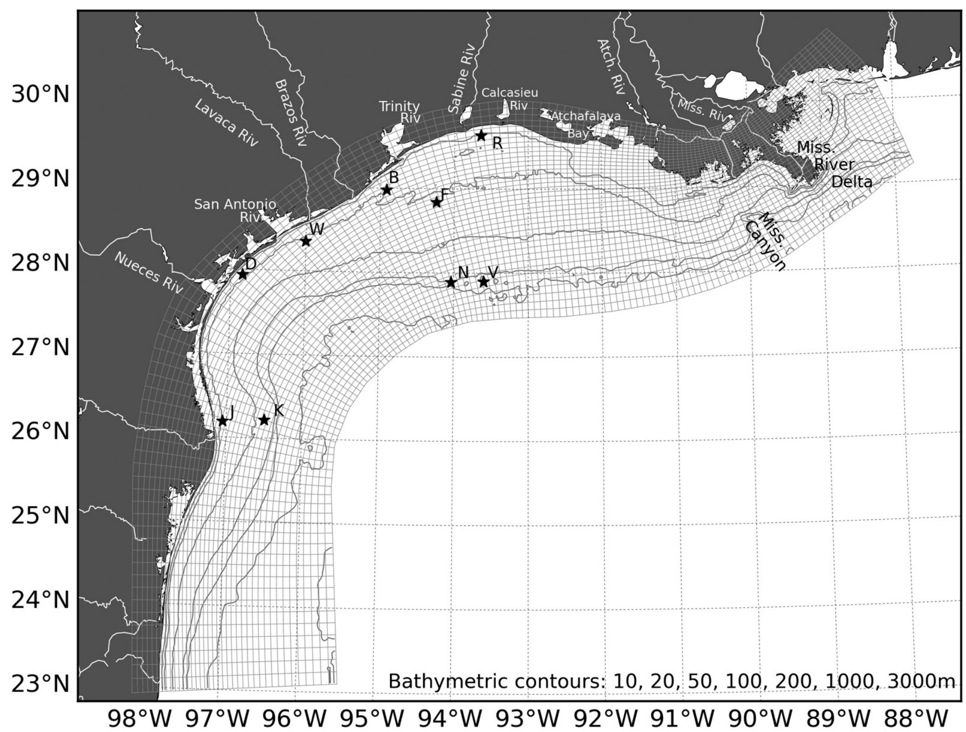


Fig 1: The numerical grid (thin grey squares) is shown in relation to bathymetry (black contours) and the location of geographic features and landmarks. For clarity, only one of five grid points is plotted in the along shore and across shore direction

Buoy	Depth (m)	Latitude (N)	Longitude (W)	Date first deployed
A*	12	29Υ31.950′	93Υ48.733′	21 Jun 1995
B	19	28Υ58.1850′	94Υ54.966′	2 Apr 1995
C*	22	28Υ48.549′	94Υ45.126′	2 Apr 1995
D	18	27Υ55.93′	96Υ48.460′	31 May 1995
E*	38	27Υ20.298′	97Υ06.000′	31 May 1995
F	24	28Υ50.153′	94Υ14.131′	22 Feb 1996
G*	12	29Υ33.985′	93Υ28.096′	11 Mar 1997
H	34	27Υ52.406′	96Υ33.367′	4 Jun 1997
J	21	26Υ11.300′	97Υ03.040′	13 May 1998
K	62	26Υ13.010′	96Υ29.930′	13 May 1998
L*	82	28Υ02.500′	94Υ07.000′	20 Apr 1998
M*	57	28Υ11.500′	94Υ11.500′	20 Apr 1998
N	105	27Υ53.382′	94Υ02.222′	20 Apr 1998
P	20	29Υ10.000′	92Υ44.250′	15 Aug 1999
R	10	29Υ38.643′	93Υ38.386′	27 Jul 1998
S*	22	28Υ26.206′	95Υ48.674′	19 Feb 1999
W	22	28Υ20.086′	96Υ01.328′	28 Nov 2001
V	27	27Υ54.018′	93Υ37.260′	23 Jan 2002

Table 1: Locations of TABS buoys

* These buoy locations have been discontinued

Fresh water fluxes from the Mississippi and Atchafalaya Rivers are specified using daily measurements of Mississippi River Transport at Tarbert Landing by the US Army Corps of Engineers. Fresh water fluxes from the other seven rivers (the Nueces, San Antonio, Lavaca, Brazos, Trinity, Sabine, Calcasieu Rivers) are prepared based on the USGS (US Geological Survey) Real-Time Water Data for the Nation. Tides are not included, but are known to be small in the region.[23] The model simulation is run for ~eight years from 2003 to 2011. It takes about nine days to integrate the simulation for one year on a cluster using 192 processors. For the pre-operational forecast model, the atmospheric forcings are changed to GFS (Global Forecast System) since NARR has neither nowcast or forecast. The horizontal resolution of GFS outputs is 0.5° and the output sampling rate is 3h.

OBSERVATIONS

The model skill was assessed based on the AVISO satellite altimetry data, Texas Coastal Ocean Observation Network (TCOON) water level observations, and the surface temperature and current measurements from the Texas Automated Buoy System (TABS) collected from 2003 to 2011. In this manuscript, the data used for validations are all operational, and model validation will focus on the velocity field to make sure the Texas and Louisiana shelf and slope model could reproduce both the seasonal and high frequency near-inertial motions.

AVISO satellite altimetry data

AVISO altimeter products are merged data combining measurements from several satellites and have a resolution of 1/3Υ × 1/3Υ. The temporal resolution of AVISO products is one day. They were produced by Ssalto/Duacs and distributed by AVISO, with support from Cnes. For more information about the AVISO product, please refer to http://www.aviso.oceanobs.com.

TCOON water level observations

TCOON is an operational coastal observation network that measures water level hourly along the Texas coast. It has expanded from its initial three stations in 1989 to over forty stations now. Most of these stations are inside the bays and estuaries. In this study, six stations in the open ocean are used to assess the model performance in producing the sea surface height near the coast. The tidal signals in the water level are removed before comparisons since this model does not include tides. For more information about the TCOON product, please refer to http://lighthouse.tamucc.edu/TCOON/HomePage.

Moored observations

The TABS is a coastal network of moored buoys (Table 1; Fig 1) that report near-real time observations about currents and winds along the Texas coast (http://tabs-os.gerg.tamu.edu) deployed and maintained by the Geochemical and Environmental Research Group at Texas A&M University.

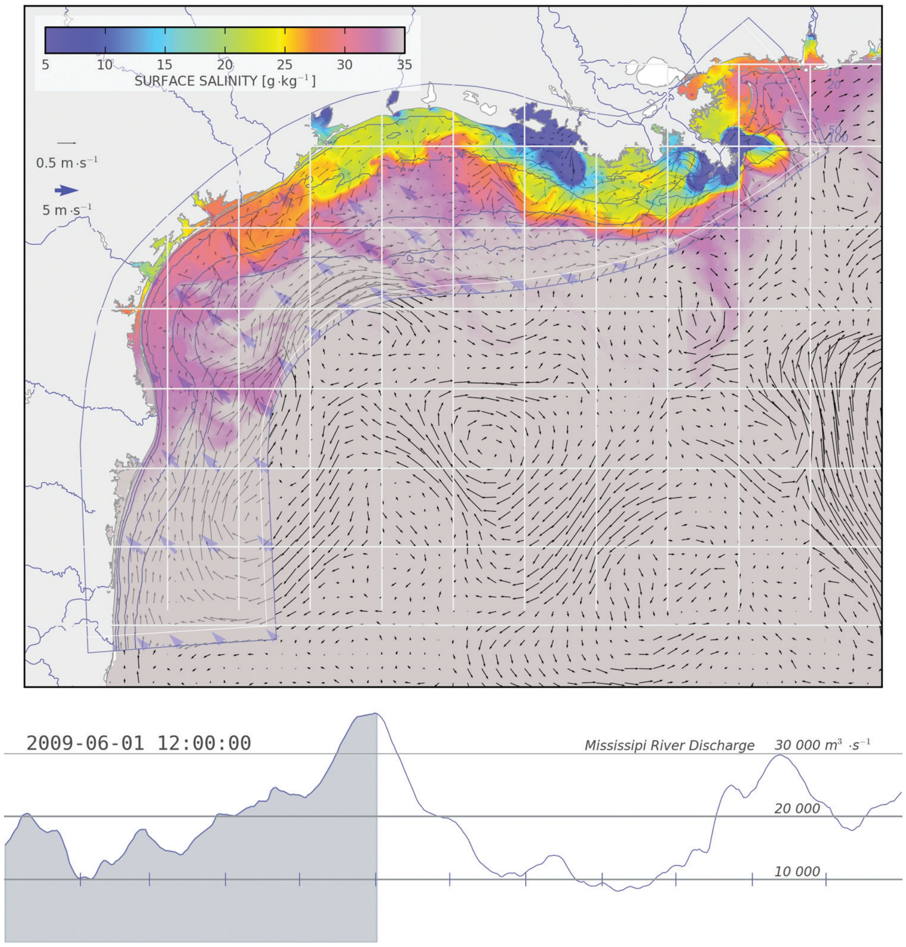


Fig 2 (a): Model-simulated sea surface salinity for 1 June 2009. The colour represents sea surface salinity. The grey errors are the surface currents, and the winds are represented by the blue errors. The ROMS results are shown in the enclosed domain. The HYCOM results are shown in the exterior. This filled line at the bottom shows the fresh water discharge from the Mississippi River

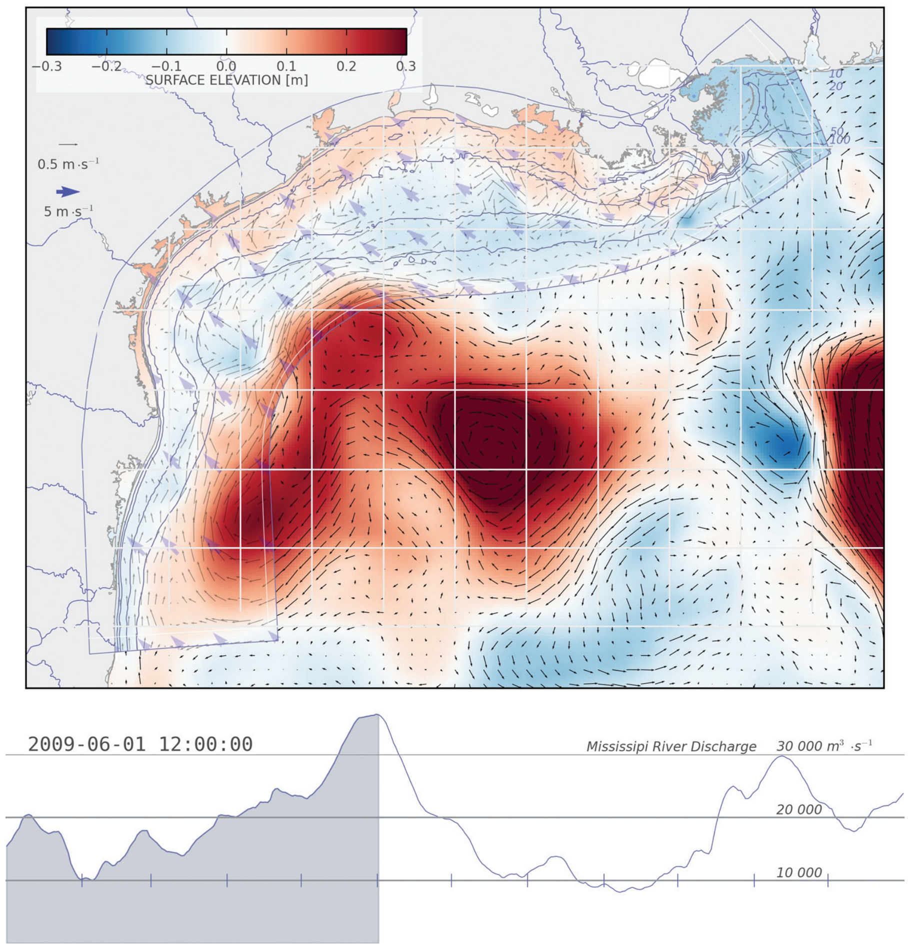


Fig 2(b): Model-simulated sea surface height for 1 June 2009. The colour represents sea surface height. The grey errors are the surface currents, and the winds are represented by the blue errors. The ROMS results are shown in the enclosed domain. The HYCOM results are shown in the exterior. This filled line at the bottom shows the fresh water discharge from the Mississippi River

Established in 1995, the primary mission of TABS is ocean observations in the service of oil spill preparedness and response. The TABS buoys measure surface temperature and velocities at ~2m below the sea surface. In this manuscript, the temperature and velocities data from 2003 to 2011 are used to assess our model performance.

MODEL SKILL

We use the model skill to quantify the ability of the model to reproduce observed currents and tracer distributions. The skill is defined as

$$skill = 1 - \frac{\sum_{i=1}^{N}(d_i - \Im[m_i])^2}{\sum_{i=1}^{N}(d_i - c_i)^2} \qquad (1)$$

where d_i are the available measurements, and $\Im[m_i]$ is a row vector of the model results in which m_i is transformed by the linear operator $\Im$ to match the measurements, c_i is a vector of climatological values.[24,25] The climatological values c_i for the velocity and tracer fields at each TABS buoy are calculated as the multi-year (2003–2011) monthly-mean average.

For a perfect model that reproduces the observation exactly, the model skill is one. If the variance of the model error (m-d), is equal to the variance of the data relative to the climatology (c-d), the skill is zero. It is possible to have a negative skill if the model error variance is larger than the data variance, ie, the model actively disagrees with observed values. A detailed description has been provided[25] of the possible interpretation of model skill under a number of different conditions.

COMPARISONS OF MODEL RESULTS AND OBSERVATIONS

In this section, the model performance is assessed with observations. First, an example is shown of the model-simulated fields. Fig 2 (a) and (b) are sea surface salinity and sea surface height with the surface current superimposed for 1 June 2009. In the enclosed region with the dark line, the colour represents the results from the hindcast ROMS model. In the exterior region, the colour represents the model output from HYCOM, which provides the realistic open boundary conditions. When applying the one-way nesting technique, a buffering zone is set up (Fig 2 white lines), where the results are gradually nudging towards HYCOM. Similar nesting procedures have been applied and validated.[26] From Fig 2, the smooth transition from ROMS to HYCOM near the open boundaries can be seen, indicating that the one-way nesting works well. Fig 2 also shows an example of the positions of the Mississippi and Atchafalaya river plumes, the LC, and the intrusions of the LCEs onto the Texas and Louisiana shelf and slope.

Comparisons with SSH observations

Comparisons with satellite altimetry

The ROMS SSH, HYCOM SSH, and AVISO satellite Altimetry are compared with each other. Several episodes are shown in Fig 3 for year 2006. The panels in the left column show the ROMS SSH with HYCOM SSH; the right panels

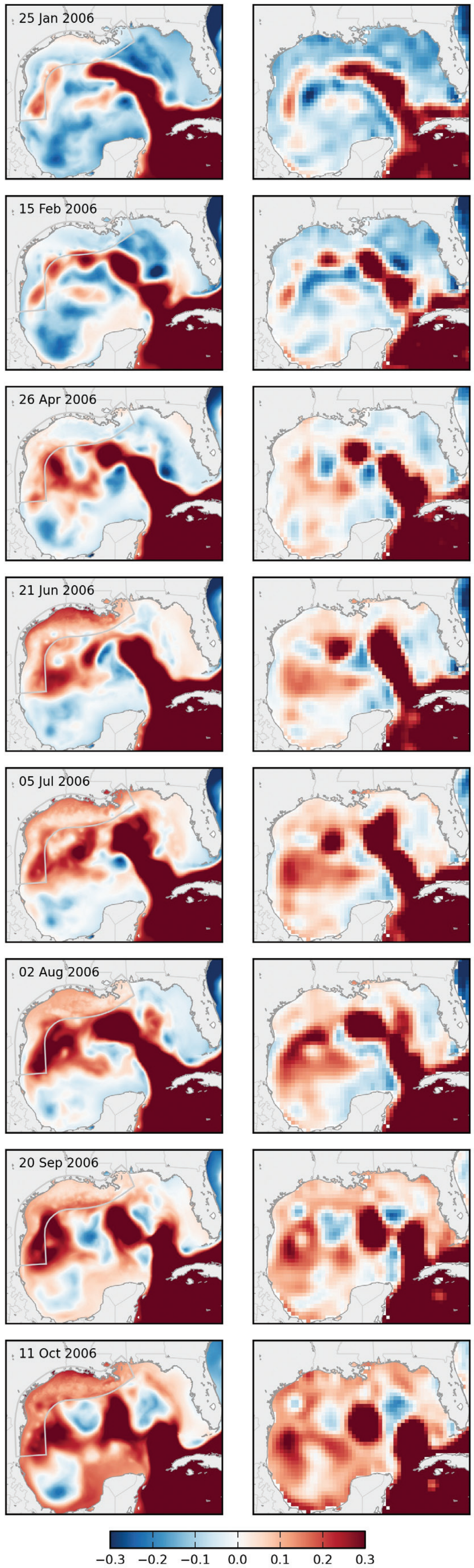


Fig 3: Comparisons of SSH from ROMS, HYCOM and AVISO satellite measurement in 2006. Left panels show the SSH from ROMS and HYCOM, respectively. Right panels show SSH from AVISO product

show the SSH from AVISO. From these figures, we can see the HYCOM SSH agrees well with the AVISO SSH. They show very similar positions for LC and LCEs. The SSHs associated with LC and LCEs are positive and typically larger than 30cm, indicating strong currents associated with these eddies. Fig 3 also shows the different phases of LCEs, ie, detaching, reattaching and shedding. The LCEs typically propagate northwestward, and interact with the TFSS regions. As for the ROMS SSH and HYCOM SSH, the continuity can again be seen of the SSH through the open boundaries.

As for a comparison between ROMS SSH and AVISO, they also display similar patterns in the Texas and Louisiana shelf and slope region (eg, 25 Jan, 15 Feb and 26 Apr 2006 in Fig 3). However, there are also some discrepancies especially near the coast regions (eg, 21 Jun and 05 Jul 2006). The ROMS SSH shows a positive value of 10cm near the coast on the Texas and Louisiana shelf and slope, while it is ~0 from AVISO. This may be explained by the following two reasons. First, satellite altimetry has larger errors in the shallow water regions;[27] second, AVISO is a relatively low-resolution global product. It has a spatial resolution of ~30km and temporal resolution of one day, while the authors' ROMS model has much higher resolution on the Texas and Louisiana shelf and slope.

Comparisons with coastal water level measurements

The satellite altimetry could not provide the coastal water level information accurately. Therefore in order to validate the water level near the coast, the model-simulated SSH is compared with the data from the TCOON coastal stations. Fig 4 shows the comparisons of model-simulated sea surface height (red line) and water levels measured from six TCOON stations (black line) in 2010. These six stations from south to north are Bob Hall Pier (27ϒ34′51″N, 97ϒ12′59″W), Port Aransas (27ϒ50′23″N, 97ϒ4′21″W), Port O'Connor (28ϒ26′45″N, 96ϒ23′45″W), Galveston Pleasure Pier (29ϒ17′6″N, 94ϒ47′17″W), Rollover Pass (29ϒ30′54″N, 94ϒ30′47″W), and Texas Point (29ϒ40′41″N, 93ϒ50′13″W), which covers most of the Texas coast line. The model is able to reproduce the coastal water level with high model skills.

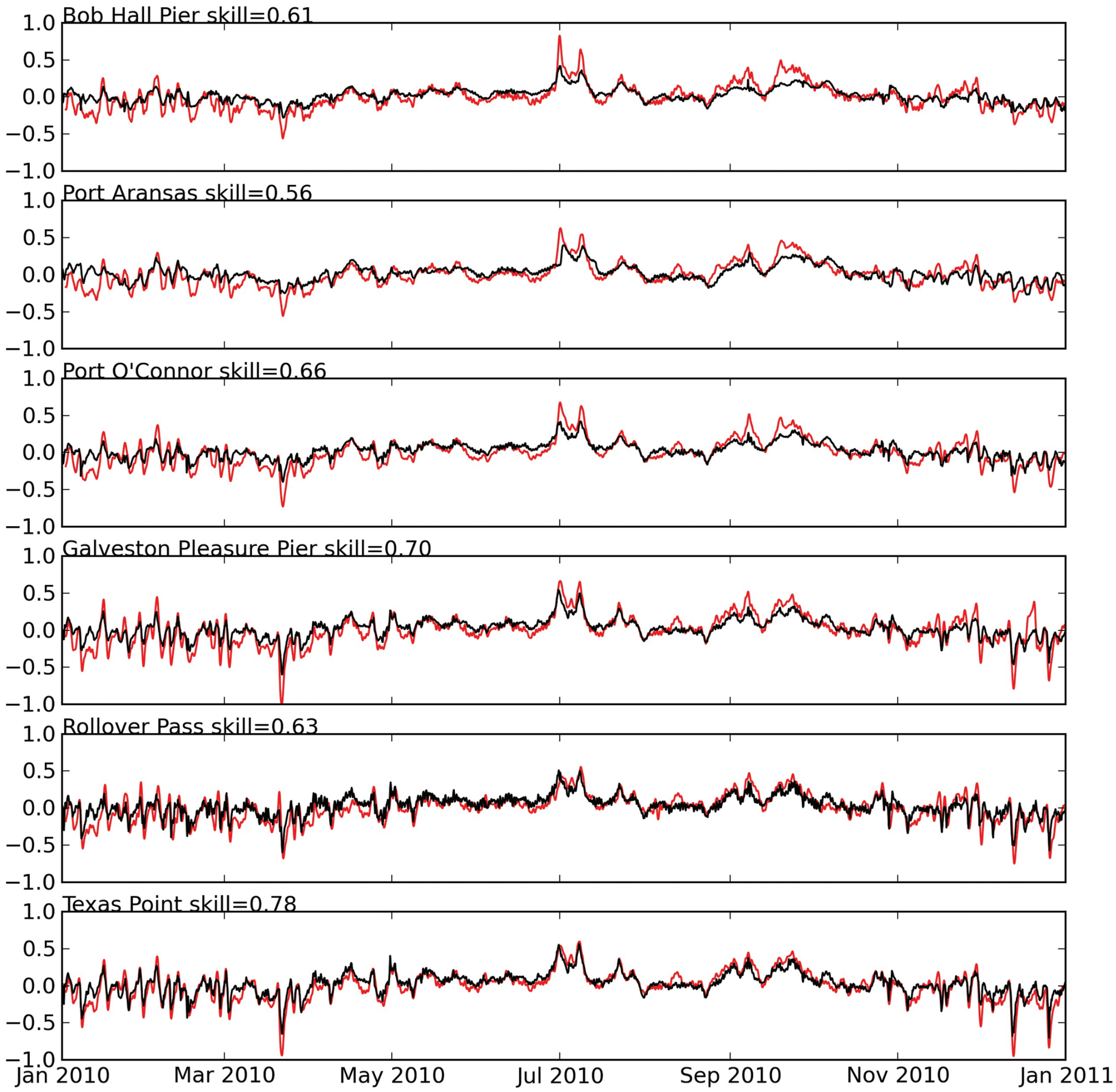


Fig 4: Comparisons of SSH from ROMS, and TCOON coastal stations in 2010. The unit for y axis (SSH) is in metres. Red line represents observations from TCOON and black line shows model result. Tidal information is removed from observations before comparisons

The skills are larger than 0.5 for all six stations indicating the model can reproduce at least 50% more variance in the data than climatology. The observed water levels at these stations display high-frequency (~daily) fluctuations in the non-summer months, and low-frequency variations (~monthly) in summer. The model is able to reproduce these patterns successfully.

Comparisons with TABS buoy temperature observations

Fig 5 shows the comparisons of model-simulated sea surface temperature and that measured from the TABS buoys for the year 2004. The model could reproduce the seasonal variability of the observed temperature well, especially at the offshore stations (buoys N and V). This is important because the seasonal variability is the dominant component comparing to other high-frequency signals. The model skills are positive at about half of the stations (Fig 5), which indicate the model can produce more variance beyond already described in the monthly climatology. For those stations near the coast, the model temperature is typically higher than observed causing a negative skill (eg, buoys B, D, and J). In summer, the model temperature is generally ~0.2ϒC higher than observed at the near-shore stations. During winter, the model-predicted temperature decreases more slowly than the buoy-observed temperature, which has negative influence on the model skill. For example, the winter sea surface temperature can drop down to ~15ϒC at the near-shore stations, and the model predicted temperature is ~1ϒC higher than observed (Fig 5). Fig 5 also shows the model lack the ability to reproduce some of the high-frequency signals shown in the data. This is probably caused by the limitation of the temporal resolution of heat flux forcing (three hours) and by the relaxation of the surface temperature to climatology.

It should be noted that while the model reproduces the seasonal pattern of surface temperature faithfully, the skill is relatively low, often negative. This is because the skill is calculated relative to the climatology. That is, the model's skill at predicting deviations from the seasonal climatology is assessed. If the skill is calculated relative to the annual mean

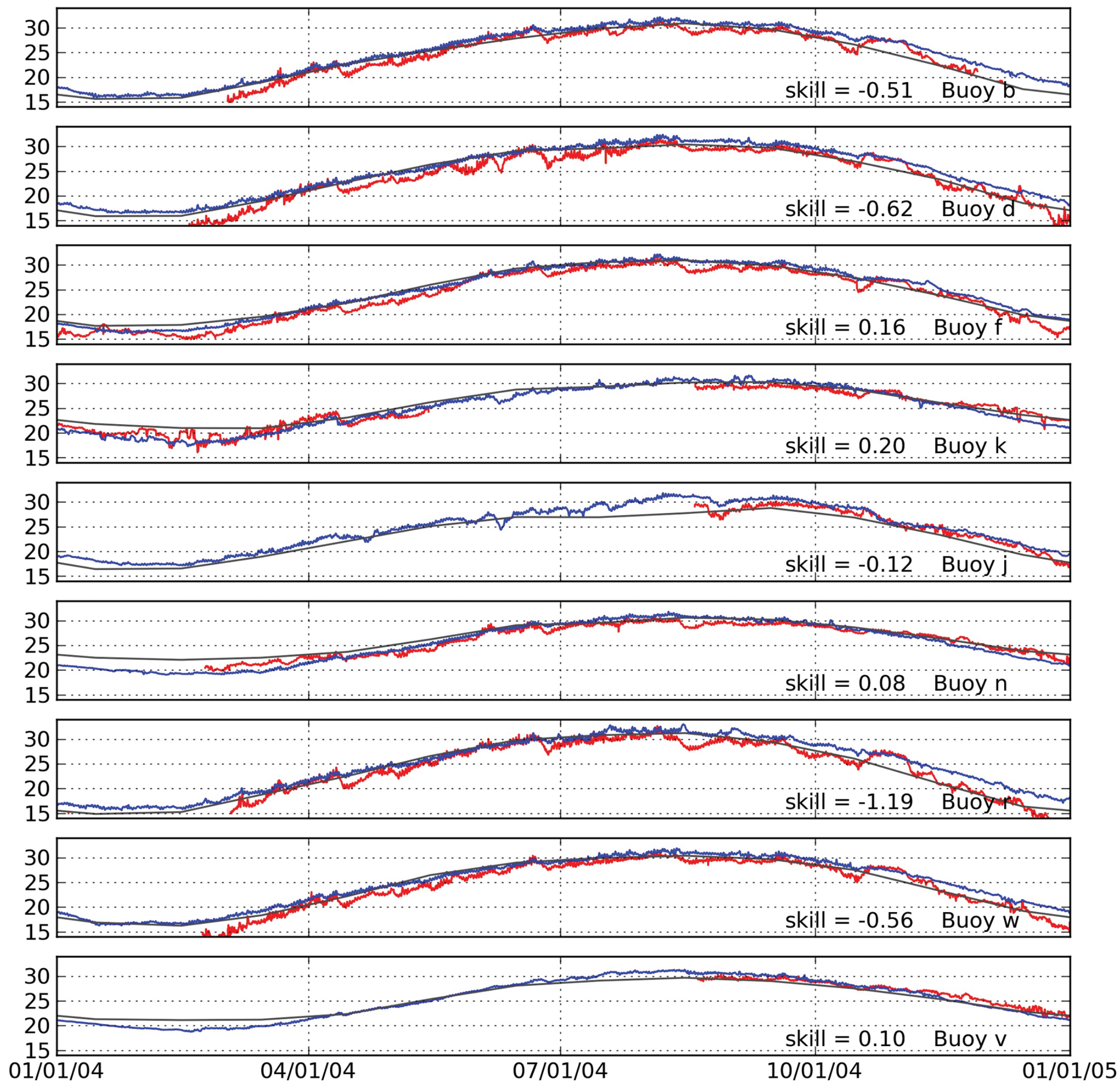


Fig 5: Comparison of temperature measurements from the TABS buoys (red) and the model simulations (blue) in 2004. The grey line represents the climatology calculated from multiple year average. The values of model skill for each buoy are also shown at the bottom-right corner

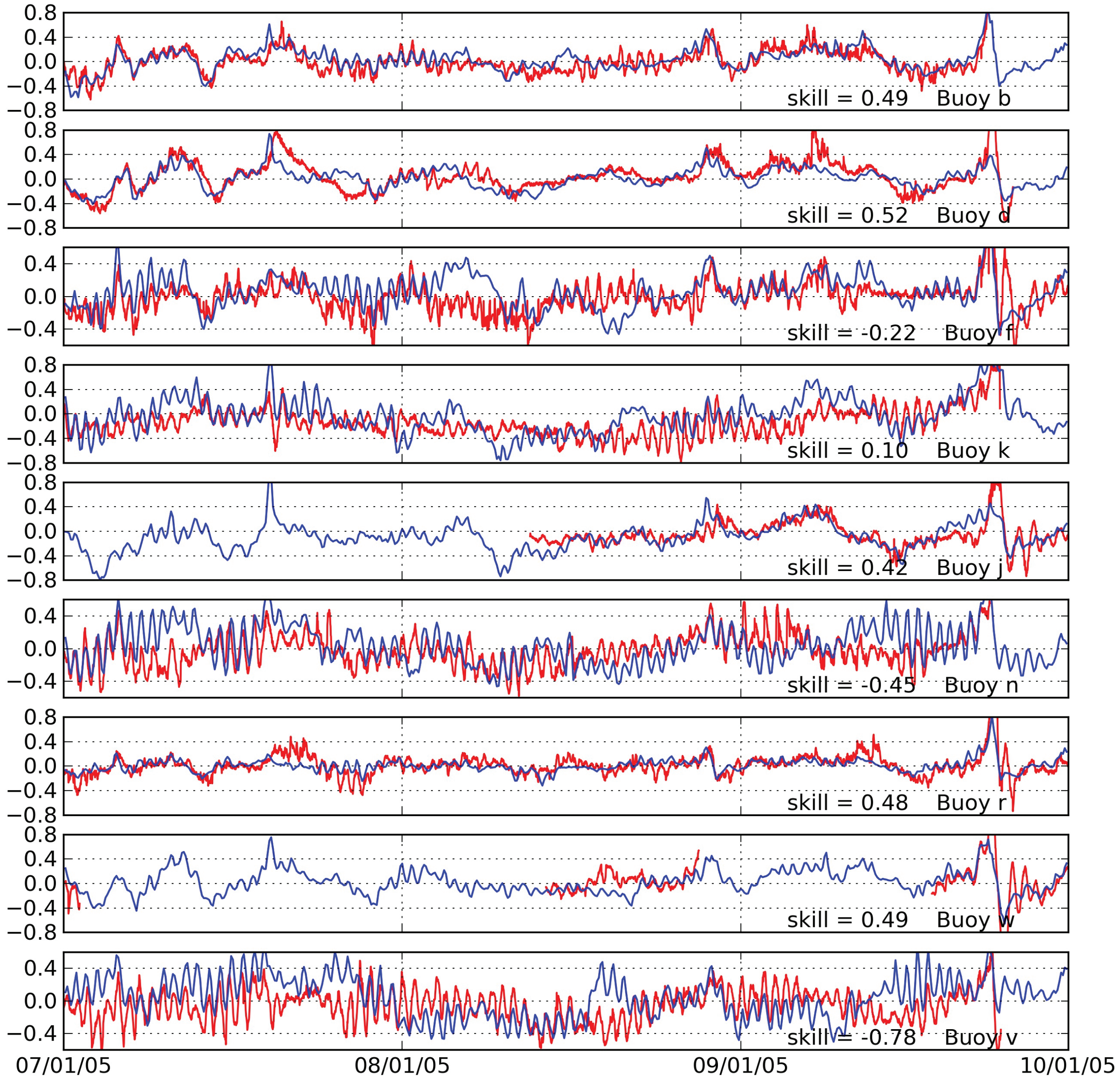


Fig 6(a): Comparison of the along-shore current component between measurements from the TABS buoys and the model simulations during the period July-Sept 2005. The values of model skill for each buoy are also shown at the bottom-right corner

temperature, the skill at all the buoy locations is above 0.9. Presently, it is not sure what causes the model errors relative to climatology. Possibilities include errors in forcings, particularly incoming short wave radiation, or variability in surface water type due to suspended sediments, which are not included in the model.

Comparisons with TABS buoy current observations

Comparisons between observed and simulated along-shore and across-shore current components at all the buoy stations are shown in Fig 6. Two three-month periods during 2003–2011 are shown when observations are available at most of the buoy stations. The model skills for currents have larger variance, ranging from ~ −1.2 to 0.7, depending on the consistency between the model current simulations and the observations. Typically, the skill for the cross-shore component has lower skill than that for the along-shore component. This is expected because the along-shore component is mainly wind-driven, and other factors (eg, pressure gradient) play a more important role in the cross-shore component, which is harder to simulate. Note: all the examples shown in this paper are compared with raw current measurements without any smoothing. If filtering is applied to the data, the model skill will be significantly increased.

Fig 6 clearly demonstrates that the model has the ability to reproduce the currents in both the weather (~2~7 days) and inertial (~1 day) bands. For the weather band currents, examples of good simulations are shown at buoys B (eg, Fig 6 a, c, and d), D (eg, Fig 6 a and c), F (eg, Fig 6 a and c), K (eg, Fig 6 a, b, and d), J (eg, Fig 6 a, b, c, and d), N (eg, Fig 6 a, b, and d), R (eg, Fig 6 a, b, and c), W (eg, Fig 6 a, c, and d), and V (eg, Fig 6 b and d).

However, in order to have an overall good skill for simulating the currents in this region, it is not enough to only

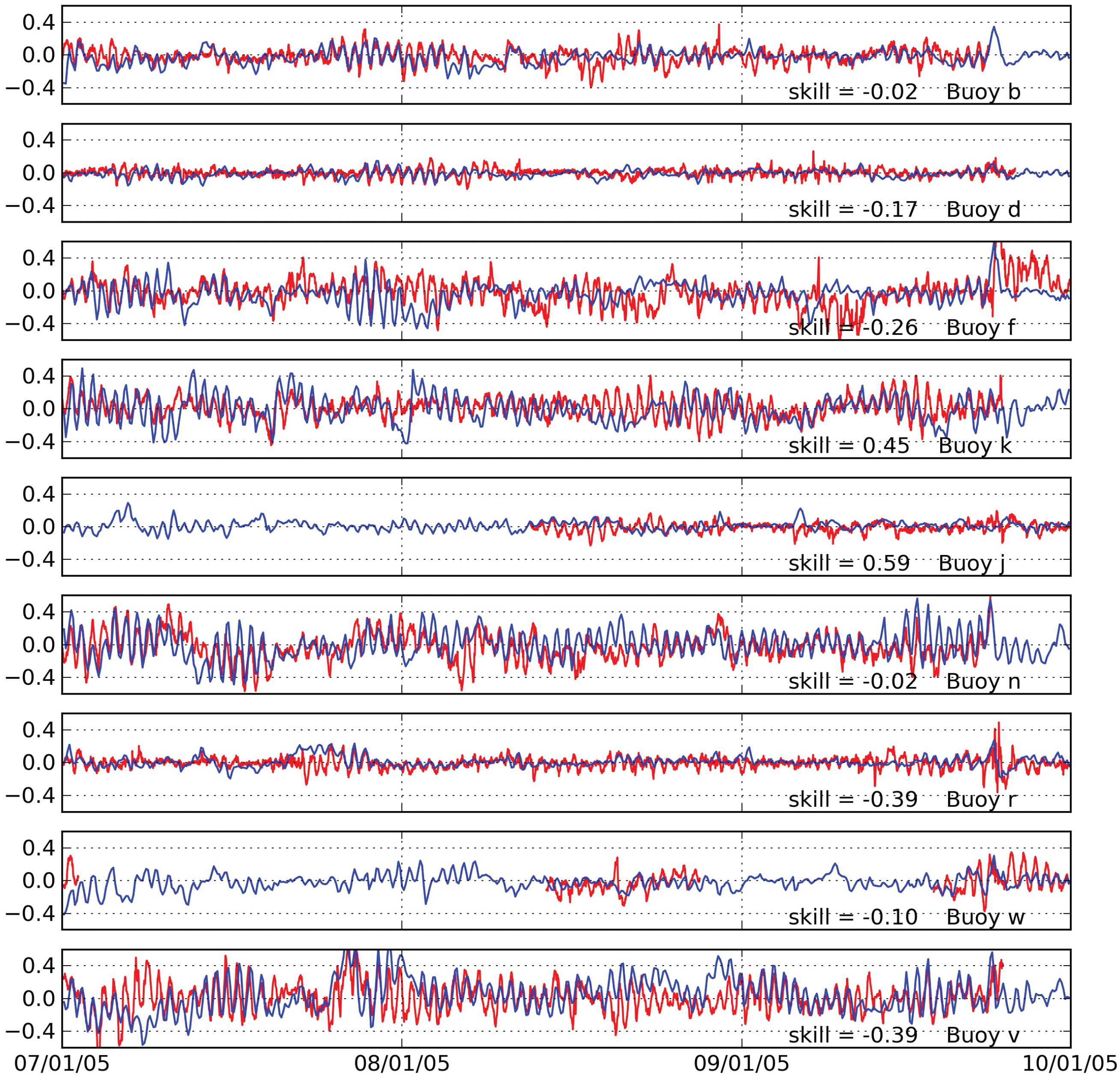


Fig 6(b): Comparison of the across-shore current component between measurements from the TABS buoys and the model simulations during the period July-Sept 2005. The values of model skill for each buoy are also shown at the bottom-right corner

reproduce the weather band current, since the sea-breeze driven near-inertial currents have been proven to be dominant and carry significant kinetic energy in this region.[12,13] An earlier version of this model (lower resolution and 1-d wind) when weather band currents are well simulated; however, the model configuration has negative skill because it can not reproduce near-inertial currents well. The model skill is significantly increased, when these energetic near-inertial currents are correctly reproduced. This also indicates that it is important to have good wind forcings, which can resolve the sea-breeze events in this region. Examples are shown for buoy K from July to September 2005, and for buoy V from April to June in 2006 in Fig 6d. The model skill reaches ~0.5 for these cases, which is a high value for the current simulation since the observed data contain all the high-frequency signals (no filters are applied to the data). There are many other good examples during the ~8-year model run, when the near-inertial motions are well simulated by the model. There are also occasions when the model predicted currents have significant bias from those observed especially at the deep buoy stations near the open boundaries (buoys K, N and V). These may be associated with the episodic low accuracy in the offshore boundary conditions.

In order to further quantify the model performance at predicting the current at both the weather and inertial bands, the coherency and phase spectra are calculated between the measured and simulated currents. As an example, Fig 7 shows the coherency and phase spectra between the measured and simulated along- and across- shore current components at the TABS stations K, J, N, and V during the period of April to June 2006, respectively. As for the inertial band, the coherency is greater than 0.6 for the along-shore current, and greater than 0.5 for the across-shore current at all these four stations, and it is much higher than the 95% significance

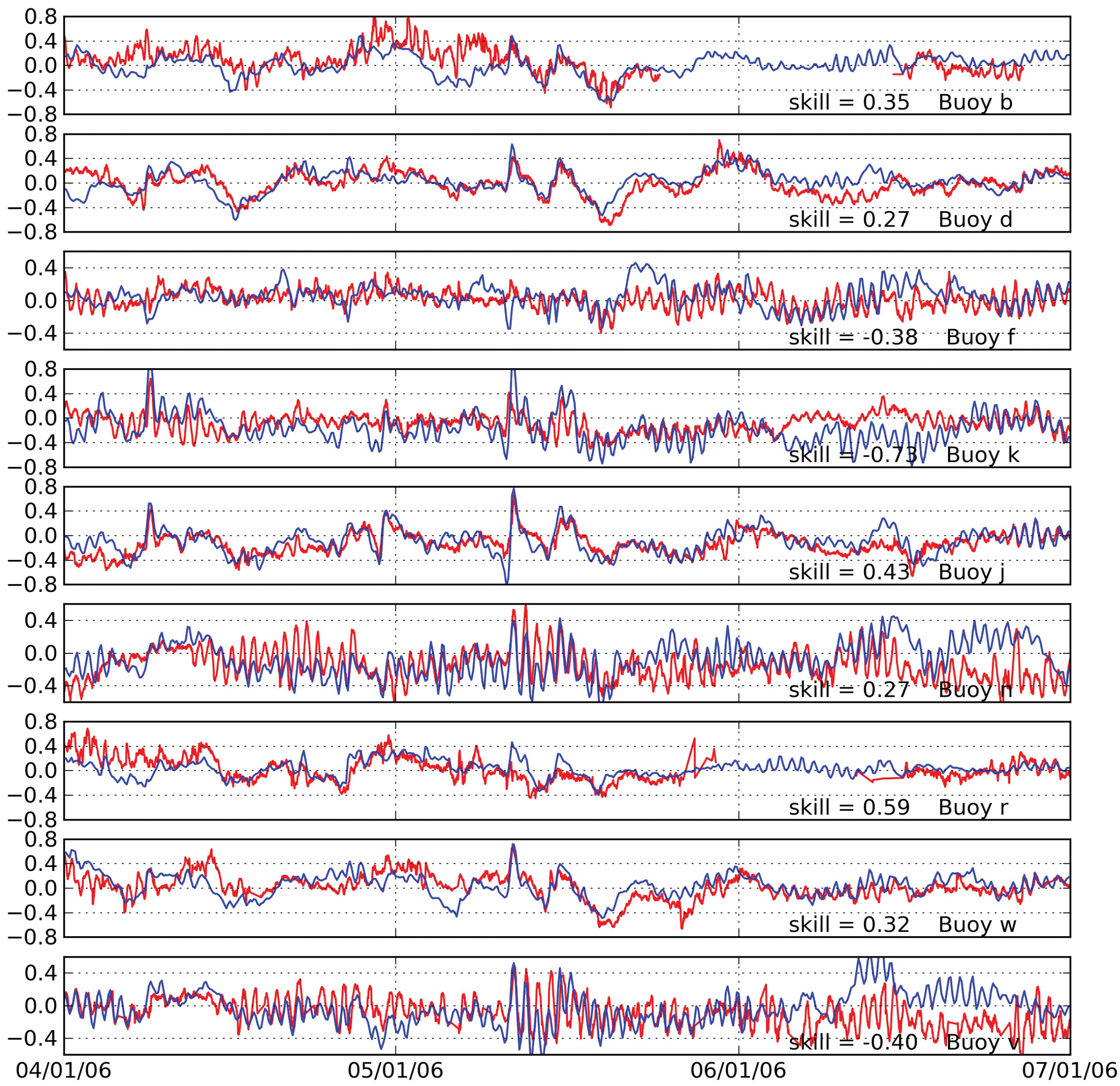


Fig 6(c): Comparison of the along-shore current component between measurements from the TABS buoys and the model simulations during the period April-June 2006. The values of model skill for each buoy are also shown at the bottom-right corner

level. The phase difference between the measured and simulated near-inertial currents are generally less than 30°, and even less than 10°s for some of the cases, which indicate the measured and simulated near-inertial currents are in phase during these time periods. These spectra analysis results can further prove that the model is able to reproduce the strong inertial band currents on the Texas and Louisiana shelf and slope. As for the weather band currents, the coherency is also high with small phase differences.

PRE-OPERATIONAL MODEL SETUP

This model parameterisation was implemented pre-operational since 1 July 2011 and since then is providing daily analysis and five days forecast. The pre-operational system is fully supported by a comprehensive set of tools written in the Python programming language. These tools create and operate the model input/output and control all the required tasks for the operationality of the ocean model. The analysis and forecast cycles are repeated continuously in a robust and fully automated manner. For a description of the Python system, also known as Operational Ocean Forecast Python Engine, see[28].

The operational engine executes daily analysis and forecast with atmospheric data from the global model Global Forecast System (GFS), a global spectral data assimilation forecast model.[29] The horizontal resolution of GFS outputs is 0.5° and the output sampling rate is 3h (the same rate is used to feed the ocean model with atmospheric data). In the future, the atmospheric data for the Texas and Louisiana shelf and slope model may be replaced by a higher resolution local atmospheric model. For a more detailed description of the usage of GFS by the operational implementation, see[30]. The lateral boundary data (temperature, salinity, currents and free surface) are obtained directly from the OPeNDAP server of

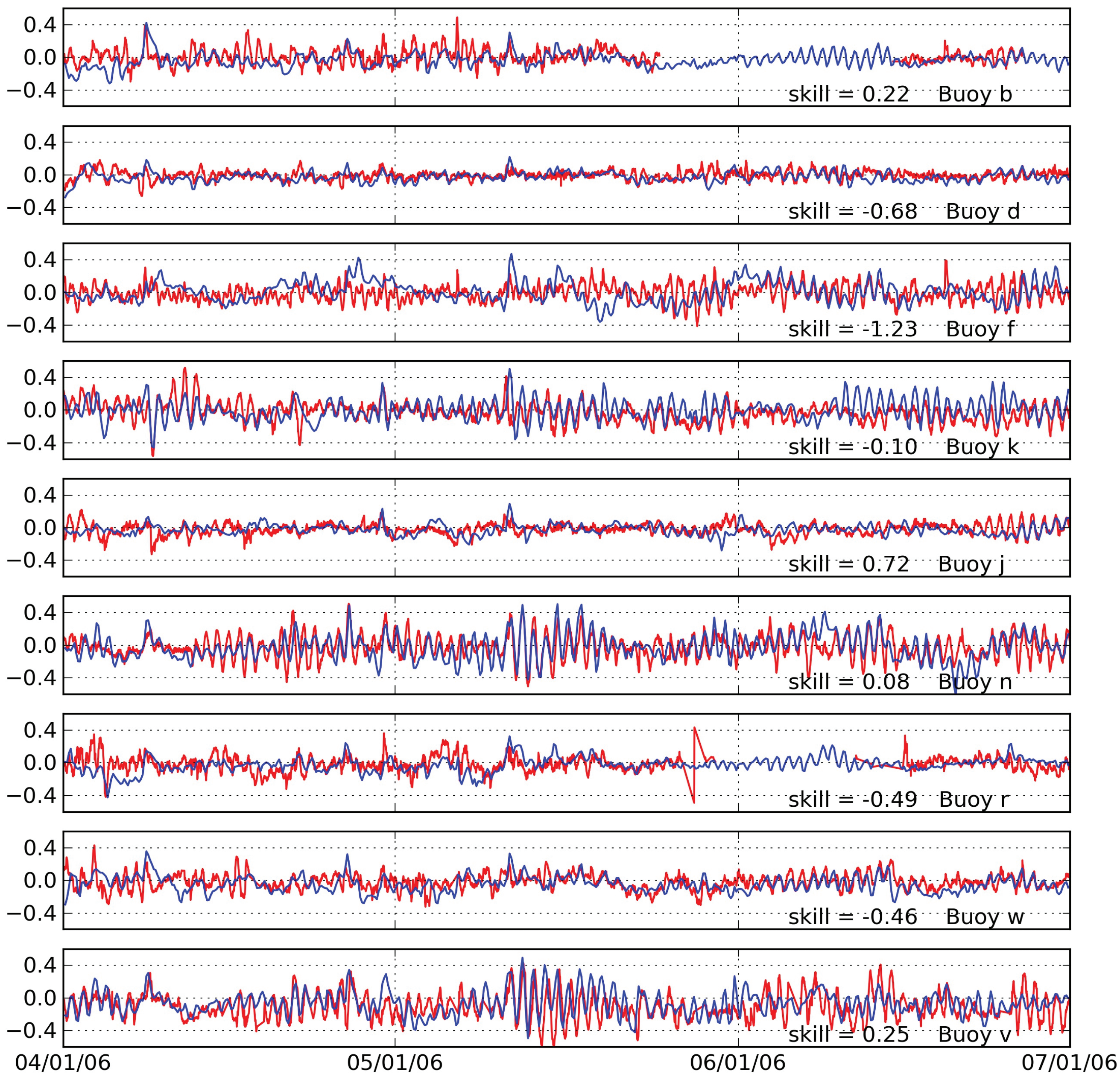


Fig 6(d): Comparison of the across-shore current component between measurements from the TABS buoys and the model simulations during the period April-June 2006. The values of model skill for each buoy are also shown at the bottom-right corner

HYCOM. The 3D fields are first interpolated horizontally to the ROMS 2D grid and subsequently interpolated from the z-consant HYCOM vertical levels to the ROMS s-levels. The 2D free surface is only interpolated horizontally. After interpolation the data are stored in the model format specifications. Freshwater discharge from nine rivers is also downloaded automatically by the operational tools.

The pre-operational results are made available through the site http://pong.tamu.edu/oof.

Their end users can visualise several ocean state variables and currents at several depths. As example of the plots available online, Fig 8 shows the analysis of sea surface salinity between 20–25 July 2011. 2011 is a year with severe flooding in the upper Mississippi; therefore the river plume is very large.

The forecast model output is also available in the local OPeNDAP server (http://pong.tamu.edu/opendap) to facilitate data extraction and visualisation from remote places without the need to download huge data files. Model 5 days forecast wind input and model output currents with sampling rate of 3h are converted every day to GNOME format. GNOME is a relocatable and very versatile oil spill model from NOAA. The GNOME-ready files allow users to predict oil trajectories in a very fast and straightforward way. These files are also available in the OPeNDAP server.

SUMMARY AND FUTURE WORK

A skill assessment of a high-resolution numerical hydrodynamic model of flow over the Texas-Louisiana continental shelf and slope shows that the model is capable of reproducing the shelf and slope scale circulations, temperature and SSH fields based on measurements collected from the TABS and satellite altimetry. The key goal of this high-resolution model is to better simulate the sea-breeze driven near-inertial

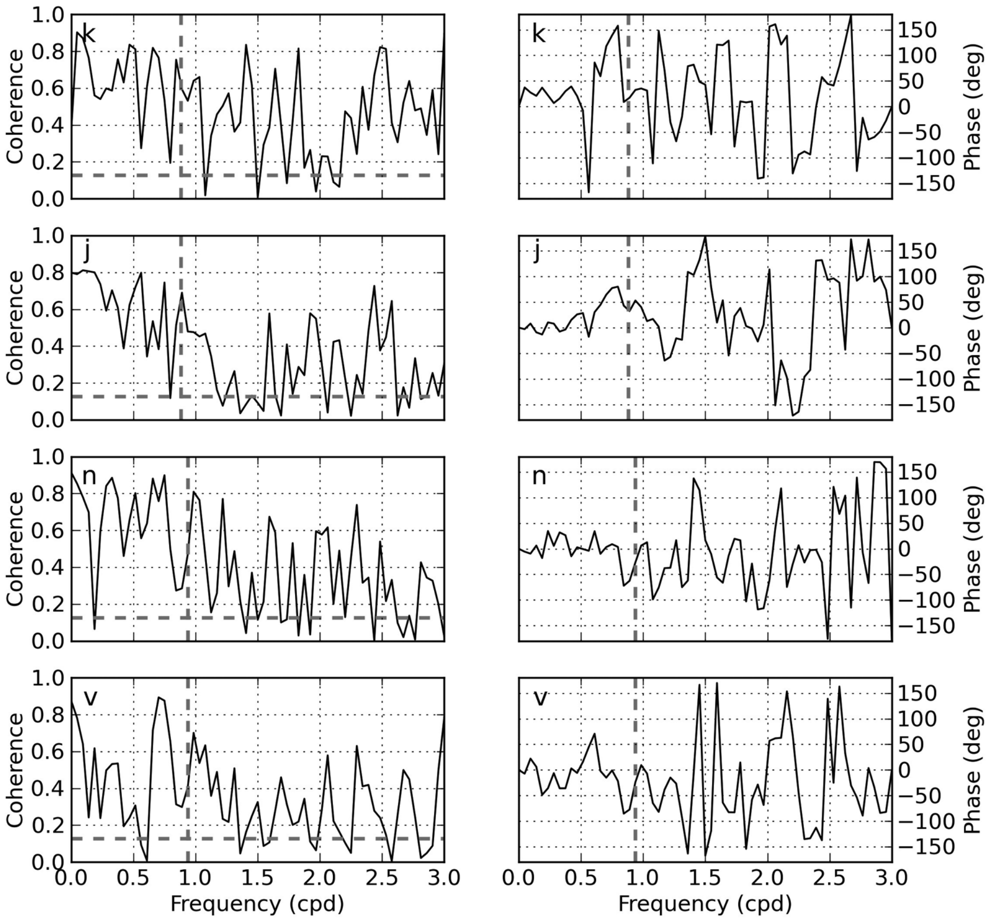
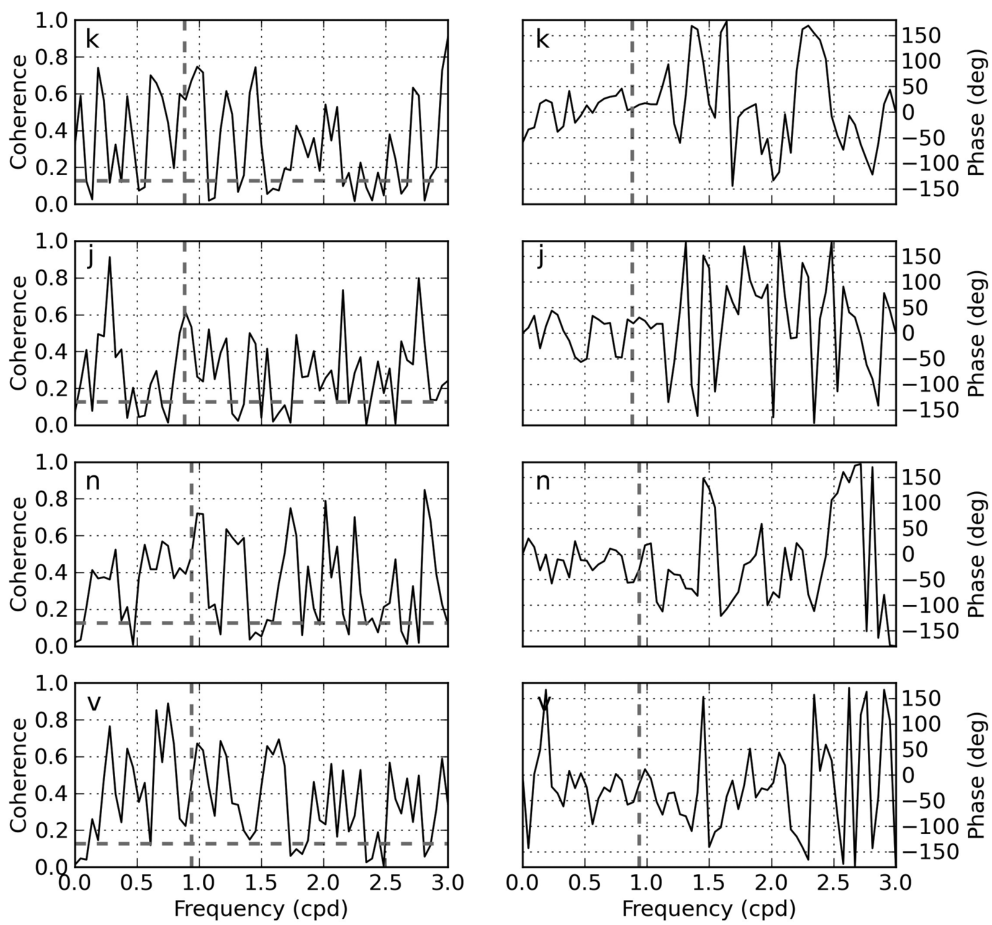


Fig 7(a): Coherency and phase spectra of the measured and simulated along-shore current component at TABS buoy stations K, J, N, and V during the period 1 Apr-30 Jun 2006. The vertical dashed lines in each panel show the location of the inertial frequency. The horizontal dashed lines in the left panels show the 95% significance level for the coherency spectra

Fig 7(b): Coherency and phase spectra of the measured and simulated across-shore current component at TABS buoy stations K, J, N, and V during the period 1 Apr- 30 Jun 2006. The horizontal dashed lines in the left panels show the 95% significance level for the coherency spectra



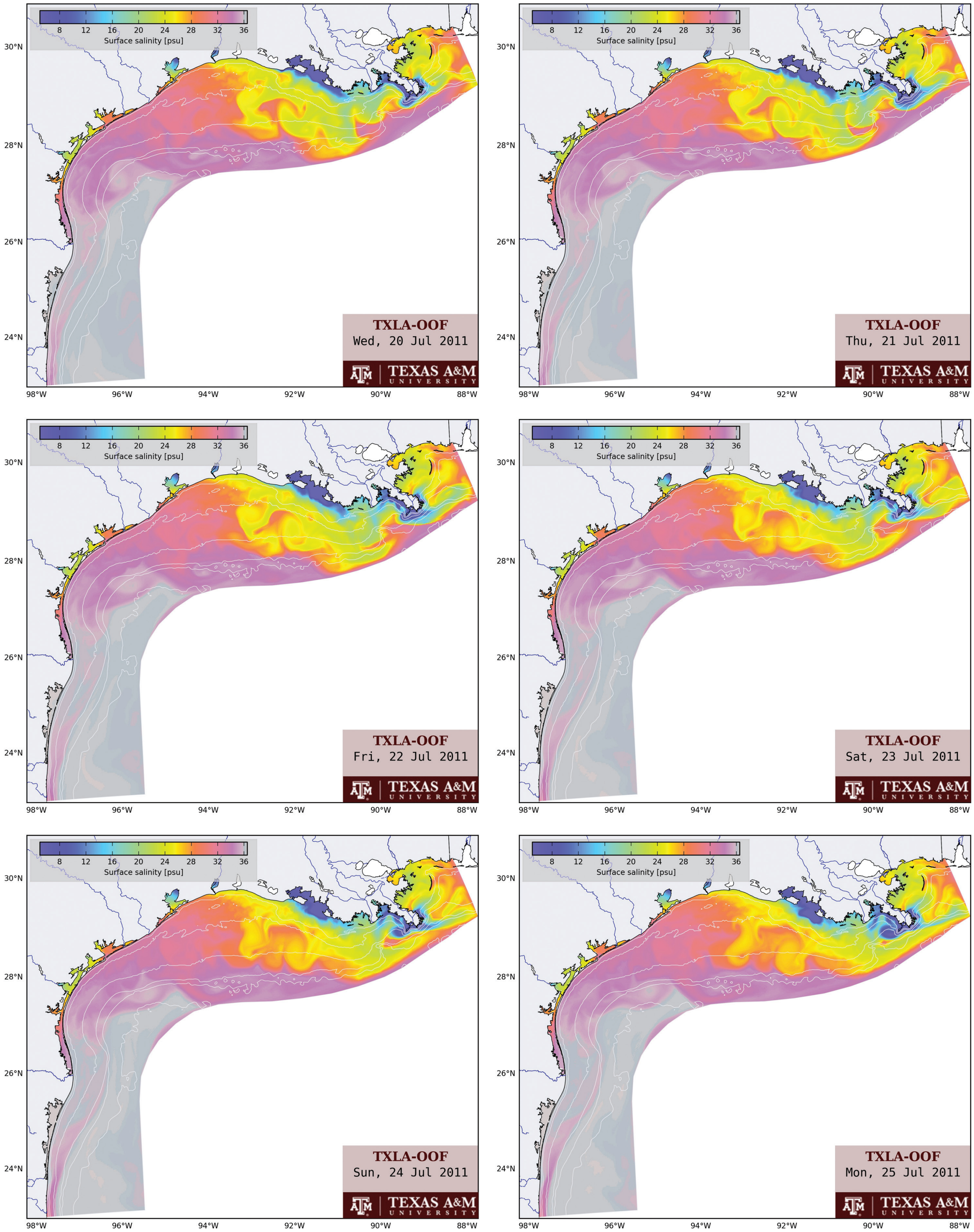


Fig 8: Analysis of surface salinity field from the operational model during the period 20–25 July 2011

motions which has been found dominant in this region in the summer months.[12,13] In this paper, the model skill is used to quantify the performance of the model, which depicts how much better the model can predict the ocean condition over the climatology. Results show that the model skill for current prediction is significantly improved because of the better simulation of the energetic near-inertial motions.

A robust pre-operational nowcast/forecast system of the Texas and Louisiana shelf and slope was created after the hindcast model was run from 1 Feb 2003 to 30 June 2011. The pre-operational modelling system starts on 1 July 2011, and is supported by the Operational Ocean Forecast Python Engine,[28] which copes with all the requirements of routine execution of the model (eg, download data from remote servers, creation of model forcings, and visualisations) making the forecast process fully automatic and robust.

The pre-operational model has many potential applications for future research. First, the authors assume that the large-scale errors in the numerical simulation are correctable, through assimilating the TABS data to their model. Second, this model may be considered a reasonable hydrodynamic foundation for regional biogeochemical and sediment transport models. To have a better understanding of the local hypoxia, this physical model could be coupled with the biogeochemical model. Third, the model-predicted surface currents could be used to track the oil spill (particularly with the currents in the GNOME format) and origins of HABS. These are all ongoing projects, and will further improve the ability of this pre-operational Texas and Louisiana shelf and slope model.

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